

Measurement of the Displacement of a Shear Mode Piezoelectric Transducer Using Laser Doppler Vibrometer

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Abstract

The ink jet print heads produced by Spectra utilize piezoelectric material's shear mode movement to deflect one pressure chamber wall, generating a pressure differential for the ejection of a drop of ink from the orifice connected with the pressure chamber. The responses of a piezoelectric transducer to the applied voltages determine the characteristics of pressure pulses that drive the jets. Direct measurement of the dynamic responses of piezoelectric transducer can provide valuable information not only for a better understanding of the shear mode movement, but also for the optimization of a print head design. It also provides reliable information to verify numerical models that can be applied quickly to various aspects of future printhead development work. However, owing to high operating frequency and tiny shear mode movement of the piezoelectric transducer the measurement is often challenging.

This paper investigates the capability of laser Doppler vibrometer in measuring the displacement of Spectra's shear mode piezoelectric transducer. Measurements have been conducted on a fully functional 128 jets, 600 dpi commercial compact print head (CCP128/600). Displacements smaller than 0.02 μm at high jetting frequency have been successfully measured. It has been demonstrated that laser Doppler vibrometer can be effectively used to evaluate printhead dynamics, identify potential problems, verify numerical models and optimize the printhead designs.

Introduction

Drop-on-demand ink jet printing is quickly becoming the technology of choice for various printer markets. Using advanced technologies in research, design and fabrication, Spectra's state-of-art shear mode piezoelectric ink jet print heads are now capable of producing high speed, high quality printers for numerous commercial and industrial printing applications. As competition in printing market continues, the drive for higher performance and more reliable printheads places stringent demands on the methods used in printhead development.

The Spectra shear mode piezoelectric printhead employs a single piezoelectric transducer to drive an array of drop-on-demand ink ejectors. A well designed transducer can maximize the shear mode displacement for maximum pressure generation. At the same time, it shall have little impact on any other pressure chambers for minimum jet-to-jet cross talk. For a long time, a direct measurement of the shear motion or vibration characteristics of the piezoelectric transducer in a functional printhead, if not impossible, has been a very difficult task due to the tiny displacement and fragile structure. An ideal instrument for the accurate detection of transducer's dynamics should be able to measure the fine movement of piezoelectric transducer in a very small region without direct contact. Meanwhile it is desirable that the response time of instrument is short enough to catch the fast movement at high frequency jetting.

Laser interferometry is an essential field of optical metrology and lends itself more and more to industrial applications because of its noncontacting nature and superior response time, resolution and accuracy. Recent advances in laser vibrometers make it possible to accurately measure the displacement and vibration in a delicate Spectra commercial compact printhead.

In this paper, we investigate the displacement of the piezoelectric transducer in different operating conditions for a 600 dpi, 128 jets CCP 128/600 printhead using laser Doppler vibrometer. Results have also been used to verify numerical models and improve the performance of printhead in the future design.

Methods

The measurement of the displacement of piezoelectric transducer was conducted on a fully functional CCP 128/600 printhead using an advanced laser Doppler vibrometer measuring system. In the sections below, details of the tested printhead, laser Doppler vibrometer measuring system and experimental setup are discussed.

CCP 128/600 Printhead

As illustrated in Figure 1, the Spectra CCP 128/600 printhead consists of an on-head ink reservoir, an array module assembly, a manifold/orifice plate assembly, and a head interface circuit board. The printhead is designed to print liquid UV light curable inks at 600 dpi resolution. A standard design can operate at a maximum printing frequency of 12 kHz. The speed may be increased considerably to meet the requirements of different applications.

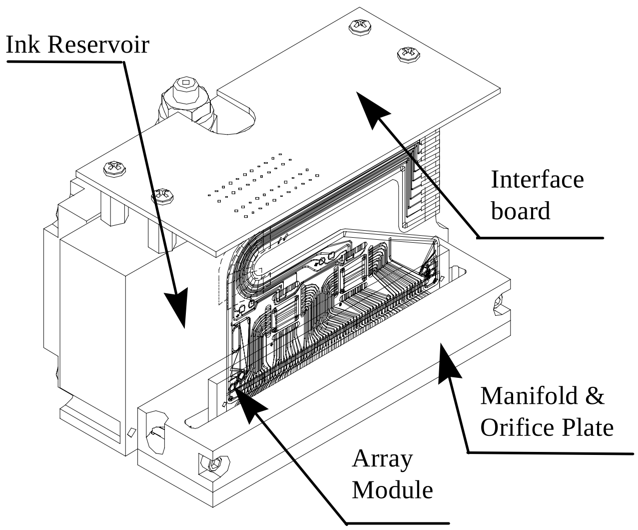

Figure 1. Spectra's 128 jets, 600dpi CCP Printhead.

The operation of this printhead is based on Spectra's shear mode technology. The heart of the printhead is a delicate array assembly. The flex circuits on each side of an array module are connected to the electrodes sputtered on the surfaces of piezoelectric transducers to provide electrical drive signals. The transducer is made of lead zirconate titanate (PZT) piezoelectric ceramics. It is epoxy bonded to the array module with multiple pressure chambers. A special designed electrode configuration can accommodate shear mode polarization patterns and make the transducer a controllable moving wall for each pressure chamber. An electrical pulse applied to a desired electrode will pressurize the ink in the pressure chamber. When the pressure wave propagates to orifice plate, a drop of ink will be ejected.

To measure the displacement of piezoelectric transducer in this study, a special window is opened on the side of manifold collar as shown in Figure 2. When the array module is installed into the manifold assembly, the surface of PZT becomes visible, allowing the laser beam to focus on any specific region of interest.

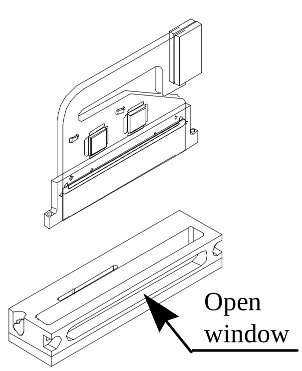

Figure 2. Modified manifold assembly with an opening on collar for the measurement of transducer's surface.

Laser Doppler Vibrometer Measuring System

The laser Doppler vibrometer measuring system used in the experiment consists of a laser optical sensor head, a sensor controller for power supply and signal processing, a printhead fire pulse generator, a CCD camera and an oscilloscope for monitoring the process. This system works according to the principles of laser interferometry. Key advantages of laser interferometry are that it is completely noncontacting and noninvasive, requiring only optical access to the surface of piezoelectric transducer. This property of requiring only optical access makes laser interferometry ideal for monitoring a print head's vibration or displacement features under normal jetting conditions.

In the laser Doppler vibrometer measuring system shown in Figure 3, a coherent He-Ne laser beam is separated into object and reference beams by a beam splitter BS1. The object beam travels through beam splitter BS2 and is then focused to a point on the surface of piezoelectric transducer. The backscattered light is diverted by BS2 towards beam splitter BS3, where the backscattered light from the object interferes with the reference beam. An acousto-optic modulator (Bragg cell) is used to introduce a frequency shift on to the reference beam, so motions towards and away from the optical head can be distinguished. The light scattered from the moving piezoelectric transducer experiences a Doppler frequency shift that is proportional to the instantaneous velocity of the transducer. The frequency difference between object beam and reference beam is clearly visible as a light intensity modulation, which can be converted to an electronic signal by the detector. The signal can then be decoded to obtain velocity or displacement.

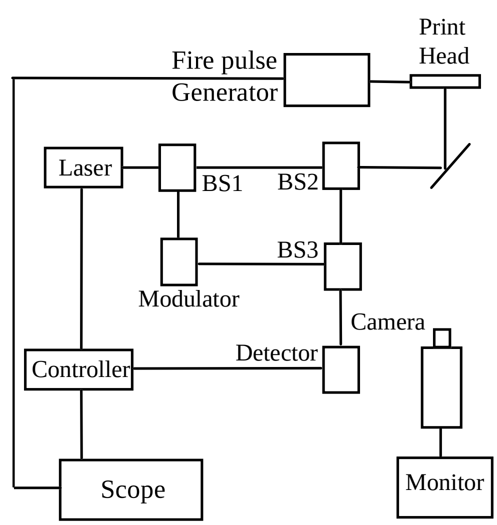

Figure 3. A schematic of the laser Doppler vibrometer measuring system.

During experiments, the laser Doppler vibrometer was mounted on a working table for precise positioning. The spot size of the laser beam is small enough such that it could be accurately focused on a single electrode on which a unipolar high voltage pulse may be applied. During the test, the measured area was constantly monitored by a video camera and the fire pulse waveform and displacement signals were displayed on an oscilloscope.

Results and Discussion

Using the CCP128/600 printhead and laser Doppler vibrometer measuring system described above, the displacements of piezoelectric transducer at various jetting conditions were investigated. Some of the test results will be discussed below.

Figure 4 shows a normalized displacement as a function of drive voltage. It is clear that the displacement increases linearly with the increase in drive voltage. This result is expected because the piezoelectric material is essentially a linear device.

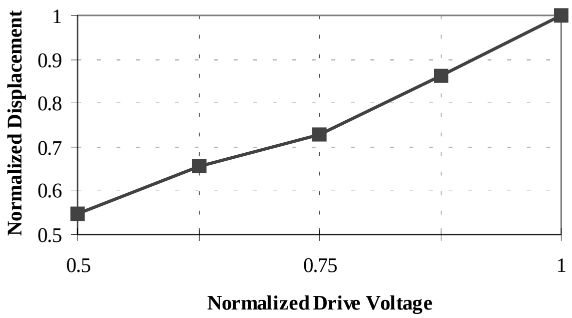

Figure 4. PZT displacement as a function of drive voltage

It has been found that the system can measure the displacement smaller than 0.02 μm at high jetting frequency. Figure 5 shows a normalized dynamic response of piezoelectric transducer measured at a jet near the center of array. The displacement is positive when the transducer moves up. This movement increases the volume of pressure chamber. It is evident from Figure 5 that, after the application of a fire pulse, the displacement increases, indicating that piezoelectric transducer shears and moves the wall of pressure chamber up. Consequently ink begins to fill the chamber. A short period of time later, displacement starts to fall, signaling the return of transducer back to its resting position. Ink in the pressure chamber is compressed during this stage and a pressure pulse is created, which is the driving force of next jet. It takes some time for the transducer to settle down completely due to a small overshoot and ringing when the fire pulse returns to ground level in the experimental pulse generator.

Figure 5. Normalized PZT displacement at an active chamber.

Jets crosstalk can alter the pumping chamber pressure. As a result drop velocity and volume may be affected, causing image defects or even jet outages. To examine the effects of jet to jet crosstalk, the displacement of inactive neighboring pressure chamber was measured. Although the displacement of crosstalk is much smaller, the highly sensitive laser Doppler vibrometer can detect the small changes successfully as we can see in Figure 6. The crosstalk becomes negligible when a measurement is made several jets away from the active chamber. Such an example is shown in Figure 7, where the displacement signal is hardly detectable.

Figure 6. Normalized PZT displacement one chamber away from the active pressure chamber.

Figure 7. Normalized PZT displacement four chambers away from the active pressure chamber.

Above examples show that laser Doppler vibrometer can provides very useful quantitative information on printhead performance. This can help us to identify the root cause of some failure modes and find countermeasures.

Spectra has been actively using numerical analysis to guide the designs of various printheads. Numerical model tests are aimed at replacing the traditional, expensive practice of physical model tests. However detailed and accurate laboratory measurements are essential towards sufficient confidence in these numerical models. Laser Doppler vibrometer is an indispensable tool to validate the numerical method and improve the accuracy of numerical models. With our coupled field finite element models, we are now able to predict the shear mode displacement well within the range for practical use.

The application of laser Doppler vibrometer is not limited to the measurement of the displacement of piezoelectric transducer in a printhead. It can reliably provide many other important features of the system dynamics, particularly the frequency responses and vibration characteristics. Spectra is constantly improving the printhead performance based on the valuable information obtained from laser Doppler vibrometer and other advanced engineering equipment and methods.

Conclusion

We have found that laser Doppler vibrometer has high sensitivity capable of detecting the dynamics of a piezoelectric transducer. Practical application of the laser Doppler vibrometer has demonstrated the viability of the approach as a very useful engineering tool for the evaluation of a printhead performance and for the optimization of future printhead design. Experimental results have enriched our knowledge on the shear mode piezoelectric printhead, verified numerical models and provided valuable information for the optimization of CCP 128/600 printhead. Spectra is continually exploring the advanced experimental methods for the development of high performance piezoelectric printheads.

Acknowledgments

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